APPLICATION FOR UNITED STATES LETTERS PATENT

for

Alternate Path Gravel Packing with Enclosed Shunt Tubes

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Alternate Path Gravel Packing with Enclosed Shunt Tubes

Background of the Invention

1. Technical Field

The present invention relates to the gravel packing of wells and in more particular relates to an apparatus for delivering a particulate-laden fluid and providing a distribution of the fluid at different levels within the wellbore annulus being packed.

2. Background

In producing hydrocarbons or the like from loosely or unconsolidated and/or fractured subterranean formations, it is not uncommon to produce large volumes of particulate matter (e.g. sand) in conjunction with the formation fluids. As is known in the art, these particles routinely cause a variety of problems that result in added expense and increased downtime. Accordingly, it is extremely important to control the production of these particulates in most operations.

Probably the most common technique for controlling the production of particulates (e.g. sand) from a well is one that is known as "gravel packing". In a typical gravel pack completion, a well screen is lowered into the wellbore and positioned across the interval of the well that is to be completed. Particulate material, collectively referred to as gravel, is then pumped as a slurry down the tubing on which the screen is suspended. The slurry exits the tubing above the screen through a "crossover" tool or the like and flows downward in the annulus formed between the screen and the well casing or open hole, as the case may be.

The liquid in the slurry flows into the formation and/or the openings in the screen that are sized to prevent the gravel from flowing through them. This results in the gravel being bridged on or "screened out" on the screen and in the annulus around the screen where it collects to form the gravel pack. The gravel is sized so that it forms a permeable mass which blocks the flow of any particulates produced with the formation fluids.

One of the main problems with gravel packing, especially where long horizontal or inclined intervals are to be completed, is obtaining equal distribution of the gravel along the entire completion interval, i.e. completely packing the annulus between the screen and the casing in cased hole completions or between the screen and the wellbore in open hole completions. Poor distribution of the gravel (i.e. incomplete packing of the interval resulting in voids/unpacked areas in the gravel pack) is often caused by the dehydration of the gravel slurry into more permeable portions of the formation interval that, in turn, causes the formation of gravel "bridges" in the annulus before all of the gravel has been placed. These bridges block further flow of the slurry through the annulus causing insufficient placement of the gravel. Subsequently, the portion of the screen that is not covered or packed with gravel is thereby left exposed to erosion by the solids in the produced fluids or gas and/or that portion of the screen is then easily blocked or "plugged" by formation particulates (i.e. sand).

U.S. Pat. No. 4,945,991, Jones, L. G., "Method for Gravel Packing Wells" discloses a screen with rectangular perforated shunt tubes attached to the outside of a screen longitudinally over the entire length of the screen. In this method, the perforated shunts (i.e. flow conduits) extend along the length of the screen and are in fluid communication with the gravel slurry as it enters the annulus in the wellbore adjacent the screen.

If a sand bridge forms in the annulus formed by the screen and the wellbore prior to placing all of the gravel, the gravel slurry will flow through the conduits past the sand bridge(s) and out into the annulus through the perforations spaced along the conduits to complete the filling of the annulus above and/or below the bridge(s). U.S. Pat. No. 5,113,935 is a further modification of this type of well screen. In some instances, valve- like devices are provided for the perforations in these conduits so that there is no flow of slurry through the conduits until a bridge is actually formed in the annulus; see also U.S. Pat. No. 5,082,052.

In many prior art, alternate path well screens, the individual perforated conduits or shunts are shown as being preferably carried externally on the outside surface of the screen; see U. S. Pat. Nos. 4,945,991; 5,082,052; 5,113,935; 5,417,284; and 5,419,394. This positioning of the shunt tubes has worked in a large number of applications, however, these externally-mounted

perforated shunts are not only exposed to possible damage during installation but, more importantly, effectively increase the overall diameter of the screen. The latter is extremely important when the screen is to be run in a small diameter wellbore where even fractions of an inch in the effective diameter of the screen may make the screen unusable or at least difficult to install in the well. Also, it is extremely difficult and time consuming to connect respective shunt tubes attached to the outside of the screen to shunt tubes attached to the outside of the following screen in the course of assembling the screen and lowering it into the wellbore.

In order to keep the effective diameter of a screen as small as possible, external perforated shunt tubes are typically formed from "flat" rectangular tubing even though it is well recognized that it is easier and substantially less expensive to manufacture a round tube and that a round tube has a substantially greater and more uniform burst strength than does a comparable rectangular tube.

An additional disadvantage to mounting the shunt tubes externally, whether they are round or rectangular, is that the shunt tubes are thereby exposed to damage during assembly and installation of the screen. If the shunt tube is crimped during installation or bursts under pressure during operation, it becomes ineffective in delivering the gravel to all levels of the completion interval and may result in the incomplete packing of the interval. One proposal for protecting these shunt tubes is to place them inside the outer surface of the screen; see U.S. Pat. Nos. 5,476,143 and 5,515,915. However, because these prior art, alternate path well screens incorporate the perforated shunts and require that holes be drilled in the wire wound portions of the screen and/or the shunt tubes, some additional form of seal between the drilled hole in the wire and shunt tube is needed to prevent slurry flow and possible erosion in the internal surface of the screen annulus formed with the base pipe. This substantially increases the cost of the screen without substantially decreasing the over all diameter of the screen. In addition, the connections between the joints of screen in these prior art well screens, require either a union type connection, which is understood by those skilled in the art, that is incapable of withstanding torque being applied, a timed connection to align all of the shunt tubes from screen joint to screen joint, a jumper shunt tube between screen joints or a cylindrical cover plate over the connection between screen joints that is either welded to the base pipe or held in

place by metal bands. All of these alternatives are expensive, time consuming and/or very difficult to handle on the rig floor while making up and installing the well screens.

Other downhole well tools have been proposed for fracturing a formation (U.S. Pat. No. 5,161,618) or treating a formation (U.S. Pat. No. 5,161,613) whereby individual conduits or shunt tubes are positioned internally within a housing or the like to deliver a particulate treating or fracturing fluid to selective levels within the wellbore. However, the outlets through the housing of these tools remain open after the particular operation is completed which would be detrimental in gravel packing completions since the produced fluids could then carry particulates back into the housing through these openings after the gravel pack has been completed and the well has been placed on production.

U.S. Pat. No. 5,333,688 discloses a gravel pack screen having shunt tubes positioned within he base pipe of the screen where they do not increase the overall diameter of the screen. Gravel slurry carried by these shunt tubes is delivered to different levels in the well annulus around the screen through the spaced outlets through the housing. However, by placing the shunt tubes within the base pipe (i.e. ultimately part of the production flowpath), an intricate and sophisticated valve is required to each of the outlets after the gravel packing operation is completed, thereby adding substantially to the costs of the screen and of installation. As well, with the shunt tubes in the production flowpath any remedial or production data gathering work will be inhibited by the tubes and will cause such work to be expensive or incapable of being performed.

<u>Summary of the Invention</u>

The present invention provides an apparatus for gravel packing an interval of a wellbore wherein there is good distribution of gravel over the entire completion interval even if a sand bridge or void or the like is formed in the well annulus before the placement of the gravel is completed. The present apparatus is similar to that disclosed in U.S. Pat. No. 4,945,991 but includes unperforated shunt means (e.g. conduits and arrangement of conduits) positioned within the annulus formed between the base pipe and the outer surface of the screen that can deliver the gravel slurry to different levels of the interval during the gravel pack operation.

This is believed to provide a more reliable means of deploying the apparatus in some applications (e.g. completion of long openhole intervals) over the prior art apparatus with the external shunts.

The present invention provides for distributing the gravel slurry to different points of the wellbore annulus from a multiplicity of unperforated flow conduits or shunt tubes positioned within the annulus formed between the base pipe and the outer surface of the screen, thereby providing the necessary alternate flowpaths for the slurry without substantially increasing the overall, outside diameter of the screen. The shunt tubes are connected to exit nozzle chambers placed at different points along the screen to allow for dispersion of the slurry around the complete circumference of the screen and along the entire length of the screen.

Also, by placing the unperforated shunt tubes within the annulus formed between the base pipe and the outer surface of the screen, a) the shunt is protected from damage and abuse during handling and installation of the gravel pack screen; b) a more desirable "round" tube can be used to form the shunt tubes thereby providing shunts with greater burst strength and less chance of failure during operation than most external shunts; c) the ability is present to increase the number of shunts and thereby provide more flow area for delivery of the gravel slurry along the completion interval; and d) an externally smooth outside diameter on the outer surface of the screen is permitted to simplify the installation of the well screen

More specifically, the well screen of the present invention is comprised of a base pipe that has multiple openings through the wall thereof and an outer surface which is spaced from the base pipe to form an annulus between the base pipe and the outer surface. Typically, multiple alternate flow paths (e.g. shunt tubes) are spaced radially around the base pipe within the annulus and extended axially along the length of the base pipe and connected to exit nozzle chambers at designated intervals along the outer surface of the screen. Solid support members are interspersed between the shunt tubes to aid in supporting and spacing the outer surface away from the base pipe.

The outer surface of the screen is comprised of a continuous length of wire wrapped around the radially spaced shunt tubes and the support members and is welded at each point of contact with the tubes and support members. Each coil of the wrap wire is spaced slightly from the adjacent coils to form fluid passages between the respective coils of wire. End rings are used to align the tubes and support members and none of the tubes or support members are welded to the base pipe. This eliminates problems associated with stress crack corrosion due to welding dissimilar metals. Multiple exit nozzle chambers are provided at designated intervals along the outer surface of the screen and the shunt tubes are connected to the exit nozzle chambers by a connector above and below. The present well screen may consist of only one section or it may consist of multiple sections that are connected together via a manifolded connector.

The manifolded connector allows for ease of make up of the joints of screen as it is run in the wellbore. The connector has multiple holes bored longitudinally through the box and pin ends. As the pin end is made up into an adjacent box end, there is a manifold area or space (e.g. common area) above the make up point that combines the flow from all of the shunt tubes. No other tie-in of the shunt tubes or additional cylindrical cover plates are required; therefore the make up is similar to conventional pipe or tubing make up as performed in daily operations. The top of the manifold area is sealed with a seal ring above and below. A slotted plate can be positioned on the box end of the connector to allow for return to the surface of the solids free carrier fluid to aid dehydration across the manifolded connector. No special tools or timed connection or welding in the area of the connector are needed or required. The joints are made up end to end without any interruption in the flow between the joints. An additional concentric sleeve is provided below the box end of the connector to provide an area for hanging the screen on slips and/or latching the rig elevators to pickup the screen joint. Slotting of the concentric sleeve can be to provide additional area for return of the slurry fluid to aid dehydration across the concentric sleeve area. These areas for return of the slurry fluid help achieve an even leak off rate across the entire well screen assembly. The top joint of the sand screen incorporates perforations in the external member of the concentric sleeve to provide the means for pumping slurry into the alternate flowpaths.

In a typical gravel pack operation, the present screen is lowered into a wellbore and a gravel slurry is pumped down through the workstring to a cross-over tool and through a perforated packer bore extension that diverts the slurry flow to the well annulus surrounding the screen and the fluid returns to the surface via the workstring and wellbore annulus. The upper end of the shunt tubes within the screen are open to the annulus via the perforated external member of the concentric sleeve to receive the gravel slurry and the tubes manifolded together at the connections.

As the gravel slurry flows downward in the well annulus around the screen, it is likely to dehydrate on the formation and the screen as gravel is deposited around the screen to form the gravel pack. If enough fluid is lost from the slurry before the annulus is completely filled, a sand bridge is likely to form that will block further flow through the well annulus. The shunt tubes in the present well screen allow the slurry to by-pass this bridge in the well annulus and thereby complete the gravel pack.

Brief Description of Drawings

The apparent advantages and improvements of the present invention, as well as, actual construction and operation will be better comprehended by referring to the drawings that are not necessarily to scale and in which like parts are identified with like numerals and in which:

Fig. 1 is an elevational view, partly in cut away, of the well screen of the present invention in an operable position within a wellbore;

Fig.1A is an elevational view, partly in cut away, of the well screen, having a slotted plate on the threaded box end for leak off, of the present invention in an operable position within a wellbore;

Fig. 2 is a partly section view of a single joint of the well screen of the present invention as set up to run in a wellbore;

Fig. 2A is a partly section view of a single joint of the well screen, having a slotted plate on the threaded box end for leak off, of the present invention as set up to run in a wellbore;

Fig.3 is a partly section view of a joint of the well screen of the present invention with several cross-sections taken along different lines of the well screen as indicated by the letters;

Fig.3A is a cross-sectional view of Fig. 3 taken along section lines AA of Fig 3;

Fig.3B is a cross-sectional view of Fig. 3 taken along section lines BB of Fig 3;

Fig.3C is a cross-sectional view of Fig. 3 taken along section lines CC of Fig 3;

Fig.3D is a cross-sectional view of Fig. 3 taken along section lines DD of Fig 3;

Fig.3E is a cross-sectional view of Fig. 3 taken along section lines EE of Fig 3;

Fig.3.1 is a partly section view of a joint of the well screen, having a slotted plate on the threaded box end for leak off, of the present invention with several cross-sections taken along different lines of the well screen as indicated by the letters;

Fig.3.1A is a cross-sectional view of Fig. 3.1 taken along section lines AA of Fig 3.1;

Fig.3.1B is a cross-sectional view of Fig. 3.1 taken along section lines BB of Fig 3.1;

Fig.3.1C is a cross-sectional view of Fig. 3.1 taken along section lines CC of Fig 3.1;

Fig.3.1D is a cross-sectional view of Fig. 3.1 taken along section lines DD of Fig 3.1;

Fig.3.1E is a cross-sectional view of Fig. 3.1 taken along section lines EE of Fig 3.1;

Fig. 4 is an enlarged sectional view, partly cut away, of the manifolded connector end portions of two adjacent joints of the well screen of Fig.1;

Fig. 4A is an enlarged sectional view, partly cut away, of the manifolded connector end portions, having a slotted plate on the threaded box end for leak off, of two adjacent joints of the well screen of Fig.1A;

Fig. 5 is a side view of the entire screen assembly in place in the wellbore and indicating the fluid flow while in the gravel packing position;

Fig. 6 is a side view of the entire screen assembly in place in the wellbore and indicating the fluid flow while in the gravel packing position with a sand bridge formed in the annulus.

Description of Preferred Embodiments.

Figs. 1and 1A illustrate the well screen 17 of the present invention in an operable position within the lower portion of a producing and/or injection well 20. Well 20 has a wellbore 25 that extends from the surface (not shown) through an unconsolidated and/or fractured production and/or injection formation 22. Even though well 20 is shown as a vertical, cased well, it should be noted that the present invention is equally applicable for use in open-hole wells and/or completions as well as horizontal and/or deviated (inclined) wellbores.

As shown, wellbore 25 is cased with casing 24 and cement 23 with perforations 21 within the interval of formation 22 that is to be gravel packed and/or fractured. Screen 17 is connected to the lower end of a cross-over tool 31 that is connected to the surface via a tubing or workstring (not shown) and is positioned across formation 22 forming an annulus 18 with casing 24.

Figs. 1-3.1 illustrate screen 17 as comprised of a perforated base pipe 1. However, because base pipe 1 is shown as having multiple perforations 14, it should be recognized that other types of base pipes, e.g. slotted pipe, etc., can be used in place of the perforated base pipe without departing from the present invention. One or more unperforated shunt tubes 7 (two shown) are spaced around the circumference of base pipe 1 and extend longitudinally along the length of the

base pipe 1. Unperforated shunt tubes 7 (i.e. flow conduits) are shown as being circular in cross-section, but it should be understood that conduits having other cross-sections (e.g. rectangular) can be incorporated without departing from the present invention.

As shown in Figs 1and 1A, outer surface 32 of screen 17 is comprised of a continuous length of wrap wire 33 that, in turn, may be shaped to provide a "keystone" profile (not shown). Solid support rods or longitudinal rod wire 34 (three shown in Fig. 1) or the like – which are commonly used in prior art screens of this general type – are interspersed with and/or between shunt tubes 7 to aid in supporting and spacing outer surface 32 (wire 33 in the preferred embodiment) of screen 17 away from base pipe 1. Shunt tubes 7 may be used as the only spacers between the base pipe 1 and the wire 33 without departing from the present invention.

Wire 33 is wrapped around the radially-spaced shunt tubes 7 and the longitudinal support rods 34 (Shown in Figs 3Eand 3.1E) on base pipe 1 and is normally welded at each point of contact with the tubes and wire rods. Each circumferential wrap of wire 33 is spaced slightly from the adjacent wraps to form passageways (e.g. slot openings) 5 between the respective wraps of wire. The wire is wrapped circumferentially in various lengths along the base pipe 1 and is shrink fit onto the base pipe 1 while covering the shunt tubes 7 and longitudinal support rods 34 forming the outer surface 32. Connector rings 16 are shrink fit onto the outer surface 32 of screen 17 and base pipe 1 to connect the outer surface 32 of screen 17 to the base pipe 1.This is basically the same process commonly used in the manufacture of wire-wrap screens that are commercially available, such as LINESLOT Screens, Reslink, Inc. Houston, Texas.

As shown in Figures 1,1A, 2, 2A, 4 and 4A, a part of the outer surface 32 of screen 17 incorporates multiple exit nozzle chambers 6 spaced along the length of each screen joint 17, shrink fitted onto base pipe 1 and comprised of several nozzles 10 (Figs. 1-4A) that are connected to the unperforated shunt tubes 7 via connectors 9. The outer surface 32 of screen 17 is connected to the exit nozzle chambers 6 via connector rings 16 that are shrink fitted on to the screen 17 and exit nozzle chamber 6.

The preceding description of screen 17 indicates that it is constructed of a perforated base pipe 1 with a wire 33 or the like that is wrapped in closely spaced wraps to form a permeable liner, it will also be recognized by those skilled in the art that outer surface 32 may be formed from a slotted pipe, screen material, or the like, as long as it is permeable to fluids and impermeable to particulates. Accordingly, the "screen" as used throughout the present specification and claims is meant to be generic and to include and cover all types of those structures commonly used by the industry in gravel pack and frac pack operations which permit the flow of fluids through them while abating the flow of particulates (e.g. commercially available screens, slotted or perforated liners or pipes, screened pipes, prepacked or dual prepacked screens and/or liners or combinations thereof) into which shunt tubes 7 can be incorporated inside the outer surface of the screen 17 as disclosed in the present invention.

Additionally, screen 17 may comprise of only one joint (e.g. 30 foot section) or it may comprise of a multiple number of joints connected together. As an example, Fig. 4 illustrates a coupling 2 for joining two screen joints 2A and 2B together. Coupling 2 is comprised of a standard threaded box 2b and a threaded pin 2a. After the two joints have been joined and properly torqued a manifold area 13 is formed above the threaded connection by the extension 2d that is threaded onto box 2b. Manifold area 13 is connected to the shunt tubes 7 from joint 2A via the channels 12 bored through exit nozzle chamber 6 above the threaded pin 2a, and is in turn connected to the shunt tubes 7 from joint 2B via channels 15 bored in the threaded box 2b. Incorporation of this manifold area 13 allows for make up of the joints 2A and 2B without having to align the shunt tubes on the adjoining joints. The bored channels 15 in the threaded box 2a connect or align with the concentric annulus 8 formed by the base pipe 1 and external concentric pipe 4 that is positioned between the top exit nozzle chamber 6 and the threaded box 2b (Fig 4).

As known by those skilled in the art, the inability to bleed off the fluid from the slurry across the coupling 2 may cause insufficient dehydration of the fluid from the gravel slurry to occur in this area and thereby an incomplete pack is performed. A nonpreferred embodiment of the present invention may incorporate area 3 for bleed off of the fluid from the slurry (Figs 1A, 2A, 3.1 and 4A). The bleed off area 3 in coupling 2 is formed by milling a groove 2c radially around the

exterior of the threaded box 2b, then covering the groove 2c by a thin slotted cover plate 3a that is held in place by the extension 2d, made up to the outside of threaded box 2b (Fig 4A). Bored hole 2e connects to bored channel 3c to allow bleed off of the fluid to the base pipe 1 (Fig. 4A). The bleed off area 3 is used when there is significant blank area between screen areas to provide bleed off of fluid that may be entrained in such area.

In a typical gravel pack operation, screen 17 is lowered into wellbore 20 (Fig.1) on workstring 32 and is positioned across the formation 22. Ball 43 is pumped onto ball seat 42 and pressure is applied through ports 51 as is understood by those skilled in the art to set packer 30. A gravel slurry 56 is then pumped down the workstring into cross-over tool 31 and out of outlet ports 31a in crossover tool 31 through ports 50 and into annulus 18 of wellbore 25. All of the shunt tubes 7 are manifolded together by concentric annulus 8 that is formed by base pipe 1 and external concentric pipe 4 to receive the gravel slurry via the wellbore annulus 18 through the ports 4a in the external concentric pipe 4.

As the gravel slurry flows downward in annulus 18 around the screen 17, it will likely dehydrate due to fluid loss to formation 22 and/or through screen 17. The fluid entering screen 17 will return to the surface through holes 14 in base pipe 1, up washpipe 55, passing through check valve 44 and through pipe 31b in cross-over tool 31 (Figs 5 and 6). As the fluid from gravel slurry 56 dehydrates on the screen 17 and/or the formation 22, gravel 57 carried in slurry 56 is deposited and collects in the annulus 18 to form the gravel pack. As is known in the art, if enough fluid is lost from slurry 56 before annulus 18 is filled, a gravel bridge 60 (Fig 6) will form and block flow through annulus 18 and prevent further filling below bridge 60. If this occurs while using the present invention, gravel slurry 56 can continue to be pumped downward into ports 4a to concentric annulus 8 and then downward through the shunt tubes 7 and out the respective exit nozzles 10 by-passing gravel bridge 60 and completing the gravel pack.

Because many varying and different embodiments may be made within the scope of the invention concept taught herein which may involve many modifications in the embodiments herein detailed in accordance with the descriptive requirements of the law, it is to be understood that the details herein are to be interpreted as illustrative and not in a limiting sense.